United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-RP-387

Results After 20 Years From a Western Larch Levels-of-Growing-Stock Study

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Abstract

Seidel, K.W. 1987. Results after 20 years from a western larch levels-of-growing-stock study. Res. Pap. PNW-RP-387. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 18 p.

The 20-year growth response from a levels-of-growing-stock study in an even-aged western larch stand in eastern Oregon, first thinned at age 33, showed that trees growing at low stand densities grew more rapidly in diameter than trees in high-density plots. Height growth was relatively uniform among density levels. Both basal-area and total cubic-volume increment increased as stand density increased. Despite the large reduction in volume increment at the low densities, most of the wood is concentrated on a few, fast-growing trees that can reach usable size sooner than slow-growing trees in high-density plots.

Keywords: Increment (stand volume), even-aged stands, stand density, thinning effects, growing stock (-increment/yield, western larch, *Larix occidentalis*.

Summary

A levels-of-growing-stock study was installed in a 33-year-old even-aged western larch stand in 1966 to provide basic growth and yield information for a wide range of stocking levels. The study is in eastern Oregon in a seral larch stand typical of the *Abies grandis/Calamagrostis rubescens* plant community. Ten plots were precommercially thinned from below to five density levels expressed as thousands of square feet of bole area per acre.

Stand density significantly affected diameter growth, which increased as growing-stock level decreased. During the 20 years after thinning, growth increased average stand diameter by 6.1 inches in low-density plots compared with 2.0 inches in high-density plots. Height growth was relatively uniform among density levels, and mortality was negligible, except in 1984 when an ice storm caused a loss of about 4 percent of the study trees at the two highest densities. Both basal-area and total cubic-volume increment increased significantly as stand density increased. Although total cubic-volume growth was greatest in high-density plots, wood was added more rapidly to fewer potentially usable trees in the low-density plots. Board-foot growth was greatest in the low-density plots because of the large amount of ingrowth from trees reaching merchantable size.

Evidence from another study (Schmidt 1966) suggests that the ideal time to precommercially thin overstocked larch stands is at 10 to 15 years of age, before crowns begin to shorten and diameter and height growth slows. As demonstrated in this study, however, considerable gains are possible from precommercial thinnings in larch stands up to 30 years of age and 45 feet tall. The proper intensity of thinning depends not only on timber management objectives but also on the importance of other forest resources to the land manager. For timber management, the primary factor influencing the residual stocking level is the manager's estimate of the minimum-size tree (diameter at breast height) that will be merchantable in the future. The larger the trees must be to support a commercial thinning, the fewer the trees that should remain after precommercial thinning; conversely, if smaller trees are merchantable, the residual stocking level should be higher. After stands reach merchantable size, density should be regulated by using the stocking-level curves prepared by Cochran (1985).

Contents

Introduction

Western larch (*Larix occidentalis* Nutt.) is an important seral species in the Blue Mountains of northeastern Oregon because of its rapid juvenile growth and desirable wood properties. Even-aged larch stands generally become established after fire or other disturbance and are often heavily overstocked. Control of stand density by thinning is an essential part of managing young larch stands. Because larch is shade intolerant, tree crowns in unthinned stands are reduced in size as early as 9 years of age; the result is a loss of vigor and a decrease in diameter and height growth (Schmidt 1966).

Although some information is available on the response of larch crop trees to thinning in Montana and British Columbia (Cole 1984, Illingworth 1964, Roe and Schmidt 1965, Thompson 1969), long-term data on growth response of managed stands to various growing-stock levels is lacking. Levels-of-growing-stock and spacing studies provide information on long-term growth and yield for managed stands so forest managers can design thinning schedules to meet timber production and multiple-use objectives. This information is also needed to construct and verify simulation models for managed stands.

This paper reports 20-year growth-and-yield results from a levels-of-growing-stock study begun in 1966 in northeastern Oregon. The study was designed to provide basic information on the growth response of young, even-aged larch stands to a wide range of stocking levels. Results for the first three 5-year periods were reported by Seidel (1971, 1977, 1982).

Study Area and Methods

The study is in the La Grande Ranger District, Wallowa-Whitman National Forest, about 15 miles southeast of Union, Oregon, at an elevation of about 4,000 feet. The stand was 33 years old in 1966 and has a site index of about 80 feet at total age 50 years.[1]

All plots were well stocked before the initial thinning; each contained at least 25,000 square feet of bole area per acre (119 square feet of basal area) (table 1).[2] There were about 1,300 trees per acre, averaging 4.5 inches in diameter at breast height (d.b.h.) and 45 feet tall. All trees were larch except for one plot at the highest density and one plot at the second-highest density where about 40 percent of the bole area and basal area left after the initial thinning was lodgepole pine (*Pinus contorta* Dougl. ex Loud.).

The soil is a Tolo silt loam, a well-drained Regosol developed from dacite pumicite originating from the eruption of Mount Mazama (Crater Lake) about 6,500 years ago. It is underlain about 3 feet down by a buried soil developed from basalt.

Ground vegetation in the study area is typical of the *Abies grandis/Calamagrostis rubescens* plant community (Franklin and Dyrness 1973). Genera of shrubs and herbs such as *Arnica, Hieracium*, and *Ribes* are common.

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[1] Site index of plots is based on curves in Schmidt and others (1976). These curves use total age (age at ground line).

[2] Bole area is a close approximation of the cambial area of the main stem. See Lexen (1943) and Smith (1962, p. 102) for discussions of the advantages of bole area as a measure of stand density.

Table 1—Stand characteristics per acre of western larch before and after the 1966, 1976, and 1986 thinnings and in 1971 and 1981

Level[a]	Density: Bole area	Density: Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height[b]	Volume[c]: Total	Volume[c]: Merchantable (including ingrowth)	Volume[c]: Merchantable (including ingrowth)
	Square feet	Square feet		Feet	Inches	Feet	Cubic feet	Cubic feet	Board feet
				BEFORE INITIAL (1966) THINNING (AGE 33)					
1	25,800	118.6	924	6.9	4.9	48.4	1,995	1,180	48
2	31,125	132.7	1,161	6.1	4.6	46.2	2,287	1,088	0
3	34,180	139.2	1,406	5.6	4.3	46.5	2,367	855	193
4	32,880	143.7	1,377	5.6	4.4	42.9	2,322	1,125	0
5	32,700	135.6	1,459	5.5	4.1	42.0	2,200	964	0
Average	31,337	134.0	1,265	5.9	4.4	45.2	2,234	1,048	48
				AFTER 1966 THINNING (AGE 33)					
1	4,708	26.0	96	21.3	7.0	48.4	474	389	48
2	9,524	49.6	215	14.2	6.5	46.2	902	648	0
3	14,242	70.9	355	11.2	6.1	46.5	1,272	782	193
4	19,313	96.4	546	8.9	5.7	42.9	1,616	1,039	0
5	24,203	109.8	745	7.6	5.2	42.0	1,847	961	0
				1971 (AGE 38)					
1	6,374	40.3	96	21.3	8.8	55.4	794	678	948
2	12,069	68.2	215	14.2	7.6	51.7	1,333	1,060	294
3	17,797	93.4	354	11.1	7.0	53.3	1,780	1,261	532
4	23,810	120.5	539	9.0	6.4	49.1	2,250	1,562	345
5	29,121	134.3	740	7.7	5.8	48.0	2,510	1,435	102
				BEFORE 1976 THINNING (AGE 43)					
1	8,730	56.3	96	21.3	10.4	62.7	1,222	1,164	3,654
2	15,207	86.1	215	14.2	8.6	56.6	1,870	1,716	2,366
3	21,716	114.8	354	11.1	7.7	58.2	2,471	2,173	1,464
4	29,244	143.9	534	9.0	7.0	55.5	3,103	2,584	1,168
5	33,917	155.7	734	7.7	6.2	53.6	3,317	2,445	706
				AFTER 1976 THINNING (AGE 43)					
1	5,078	34.2	51	29.2	11.1	64.9	760	731	2,876
2	10,006	59.3	129	18.4	9.2	62.8	1,301	1,216	2,368
3	15,012	82.7	225	13.9	8.2	62.7	1,808	1,627	1,464
4	20,029	104.0	333	11.4	7.6	60.9	2,248	1,957	1,168
5	24,779	121.0	464	9.7	6.9	61.7	2,621	2,138	706
				1981 (AGE 48)					
1	6,592	44.6	51	29.2	12.6	72.8	1,146	1,116	5,110
2	12,505	72.9	129	18.5	10.3	68.9	1,862	1,770	4,949
3	18,737	99.3	224	13.9	9.0	67.8	2,412	2,264	3,583
4	24,433	121.2	329	11.6	8.3	66.4	2,986	2,740	2,797
5	29,960	137.6	462	9.8	7.4	66.0	3,398	2,959	1,357
				BEFORE 1986 THINNING (AGE 53)					
1	7,582	52.7	51	29.2	13.8	74.7	1,514	1,484	7,583
2	14,363	82.9	128	18.6	11.0	69.6	2,294	2,202	8,915
3	21,158	110.9	220	14.1	9.6	68.7	2,962	2,814	7,253
4	27,185	132.9	318	11.8	8.8	67.9	3,625	3,480	5,628
5	30,847	137.8	408	10.4	7.9	69.4	3,858	3,549	3,028
				AFTER 1986 THINNING (AGE 53)					
1	5,056	36.4	32	37.4	14.7	78.6	1,065	1,044	5,463
2	10,147	59.9	87	22.5	11.3	71.3	1,671	1,604	7,197
3	15,091	81.5	148	17.2	10.0	71.5	2,206	2,096	6,200
4	19,945	101.7	218	14.3	9.4	70.0	2,776	2,665	5,269
5	25,042	115.1	313	11.9	8.2	71.3	3,241	2,982	2,899

[a] Two plots for each density level.

[b] Average height of trees measured with dendrometer (about 15 trees per plot).

[c] Total cubic-foot volume—entire stem, inside bark, all trees; merchantable cubic-foot volume—trees 5.0-inch d.b.h. and larger to a 4-inch top diameter inside bark (d.i.b.); board-foot (International 1/4-inch rule) volume—trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.

Figure 1—A plot after initial thinning in 1966 to an average spacing of 14 feet. Bole area is about 10,000 square feet per acre, and basal area is about 50 square feet per acre.

The experiment is a levels-of-growing-stock study designed for thinning at 10-year intervals. It consists of a completely randomized design with two replicates of five levels of growing stock installed on ten 0.4-acre plots (each surrounded by a 30-foot-wide buffer strip). The growing-stock levels selected for testing were 5,000, 10,000, 15,000, 20,000, and 25,000 square feet of bole area per acre. Actual stand densities after thinning in terms of bole area and basal area are given in table 1. The two plots assigned to each density level were thinned to about the same bole-area level in 1966, 1976, and 1986.

In general, plots were thinned from below to leave the required number of largest and most vigorous trees as evenly spaced as possible (fig. 1). None of the slash from the thinnings was removed from the plots.

Diameters of all plot trees were measured to the nearest 0.1 inch after the 1965, 1970, 1975, 1980, and 1985 growing seasons. On each plot, about 15 trees, proportionately distributed over the range of diameters, were measured with an optical dendrometer in 1966, 1970, 1975, 1980, and 1985. Some of the trees chosen in 1966 have been cut in subsequent thinnings and replaced with other trees. The measurements were used to develop an equation expressing volume and bole area of the entire stem inside bark as a function of diameter. New coefficients were calculated after each measurement and used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the four 5-year periods (1966-70, 1971-75, 1976-80, and 1981-85). Height growth of trees chosen for volume-equation measurements was also measured by dendrometer.

Split-plot-in-time analyses of variance were used to test for significance of treatment effects. Tukey's test was used to determine significant differences among treatment means. Nonlinear regression analyses related diameter, basal area, and volume growth to residual bole area and basal area. The curvilinear model is the same one used in the earlier reports of this study:

$$Y = a + b\,(1 - e^{-cX})^{d};$$

where:

Y = diameter, basal area, or volume growth;

X = residual bole area or basal area;

e = natural base of logarithms = 2.71828....; and

a,b,c,d = regression coefficients.

Results and Discussion

Diameter Growth

Diameter growth consistently responded to changes in stand density during all four 5-year growth periods. Average growth was greatest on the most heavily thinned plots and decreased as stand density increased (table 2), partly because of more small, slow-growing trees in the high-density plots. The periodic annual diameter-growth rate at the lowest density was three to four times the growth at the highest density during the 20 years of the study. Differences in rates of diameter growth between the lowest density and all others were significant ($P<0.01$) for each 5-year period. Significant differences also were found between some other densities (2 vs. 4, 2 vs. 5, and 3 vs. 5).

Diameter growth was greatest during the first period at each density level, intermediate during the second and third, and slowest during the fourth (table 2). Growth in the first period was significantly greater ($P<0.01$) than in any of the later periods, and growth in the fourth period was significantly less than in any of the earlier periods. No significant differences in growth existed between the second and third periods. A significant interaction ($P<0.05$) was found between growth periods and density levels, probably because growth was greater during the second period at some levels; at other levels, growth was greater during the third period, although differences were small.

A significant ($P<0.01$) curvilinear relationship was found between periodic annual diameter increment and bole area or basal area at the beginning of each growth period (figs. 2 and 3). Bole area and basal area each accounted for about 98 percent of the variation in diameter growth between plots during the first three periods and for about 90 percent of the variation during the fourth period. The excellent correlation between diameter growth and stand density suggests that land managers can predict—with a reasonable degree of confidence—periodic annual diameter-growth rates after thinning 33- to 48-year-old larch stands of site index 80.

Table 2—Periodic annual increment and mortality per acre of western larch by age and density level after thinning at age 33 and 43

	Residual density			All trees											75 largest trees	
				Basal area growth			Total volume growth			Merchantable volume growth (including ingrowth)						
Density level	Bole area	Basal area	Diameter growth[a]	Net	Mortality	Gross	Net	Mortality	Gross	Net	Mortality	Gross	Ingrowth		Diameter growth[a]	Gross total volume growth
	Square feet		*Inches*	*- - Square feet - -*			*- - Cubic feet - -*			*- - Board feet - -*			*Board feet*	*Percent*	*Inches*	*Cubic feet*
AGE, 33-38 YEARS (1966-70)																
1	4,700	26.0	0.36	2.86	0	2.86	64	0	64	180	0	180	170	94.4	0.36	54
2	9,500	50.0	.23	3.72	0	3.72	86	0	86	59	0	59	59	100.0	.27	40
3	14,250	71.0	.18	4.50	.03	4.53	102	1	103	68	0	68	43	63.2	.24	31
4	19,300	96.0	.14	4.82	.19	5.01	127	4	131	69	0	69	69	100.0	.22	30
5	24,200	110.0	.11	4.90	.17	5.07	133	3	136	22	0	22	22	100.0	.19	28
AGE, 38-43 YEARS (1971-75)																
1	6,400	40.0	.32	3.20	0	3.20	85	0	85	541	0	541	403	74.5	.33	73
2	12,100	68.0	.19	3.58	0	3.58	107	0	107	414	0	414	374	90.5	.20	48
3	17,800	93.0	.15	4.28	0	4.28	138	0	138	186	0	186	130	70.2	.18	48
4	23,800	120.1	.12	4.69	.16	4.85	170	3	173	164	0	164	125	76.2	.16	44
5	29,100	134.0	.08	4.29	.11	4.40	161	2	163	120	0	120	96	80.0	.14	32
AGE 43-48 YEARS (1976-80)																
1	5,078	34.0	.31	2.07	0	2.07	78	0	78	447	0	447	129	28.1	.31	78
2	10,006	59.0	.20	2.73	0	2.73	113	0	113	517	0	517	333	66.4	.22	79
3	15,012	83.0	.15	3.32	0	3.32	121	0	121	424	0	424	323	76.6	.18	55
4	20,029	104.0	.13	3.44	.05	3.49	147	1	148	326	0	326	227	73.1	.15	51
5	24,779	121.0	.10	3.32	.06	3.38	156	1	157	131	0	131	101	77.4	.13	44
AGE, 48-53 YEARS (1981-85)																
1	6,592	44.6	.22	1.62	0	1.62	74	0	74	495	0	495	0	0	.22	74
2	12,505	72.9	.14	2.00	.07	2.07	86	2	88	793	0	793	426	54.5	.15	64
3	18,737	99.3	.12	2.32	.33	2.65	110	8	118	734	0	734	376	52.8	.14	64
4	24,433	121.2	.10	2.35	.66	3.01	128	16	144	566	0	566	361	66.8	.13	53
5	29,960	137.6	.07	0.04	2.37	2.41	92	56	148	335	0	335	212	61.3	.11	51

[a] Arithmetic diameter growth of trees living through four 5-year periods (1966-70, 1971-75, 1976-80, and 1981-85).

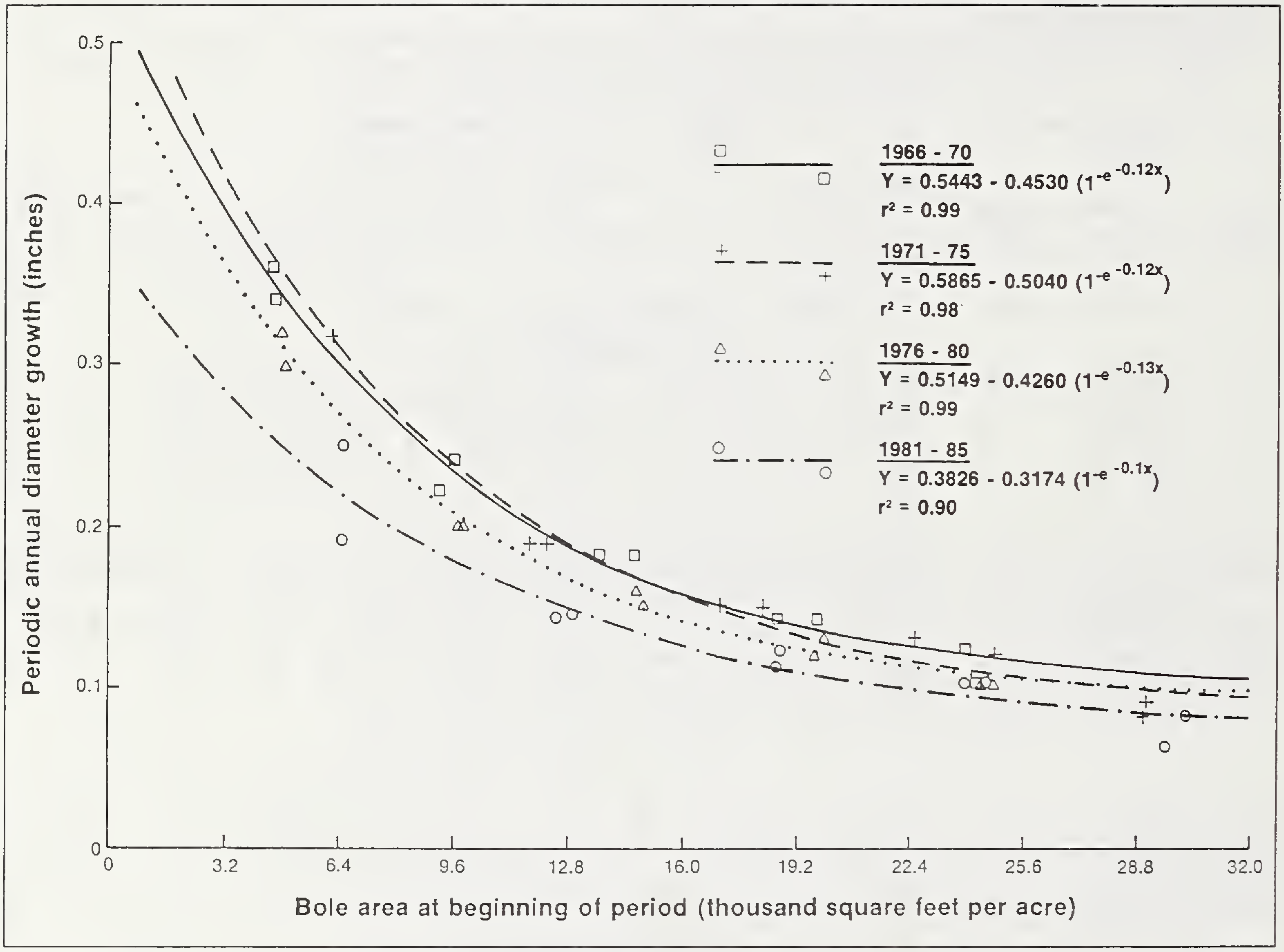

Figure 2—Periodic annual diameter growth by density level (bole area) and growth period.

The effect of the second thinning in 1976 was to prevent the normal decline in diameter growth associated with age and increased stand density, rather than to increase growth above that of the previous period. This result suggests that frequent thinnings (about every 5 years) are neccessary if a uniform rate of diameter growth is to be maintained. A uniform diameter-growth rate cannot be maintained indefinitely by repeated thinnings, but it appears to be attainable to at least a stand age of about 50 years.

During the 20 years of this study, the mean stand diameter increased by 9.8 inches in the lowest density plots and 4.1 inches in the highest density plots (table 3). About one-half of this increase was the result of removing the smallest trees during the three thinnings. Because of cutting the small, slow-growing trees and fast growth on the residual trees in the lowest density plots, the mean diameter in these plots was 79 percent greater in 1986 than in the highest density plots (14.7 vs. 8.2 inches) (table 1). Diameter growth of larch and lodgepole pine was similar during all four periods.

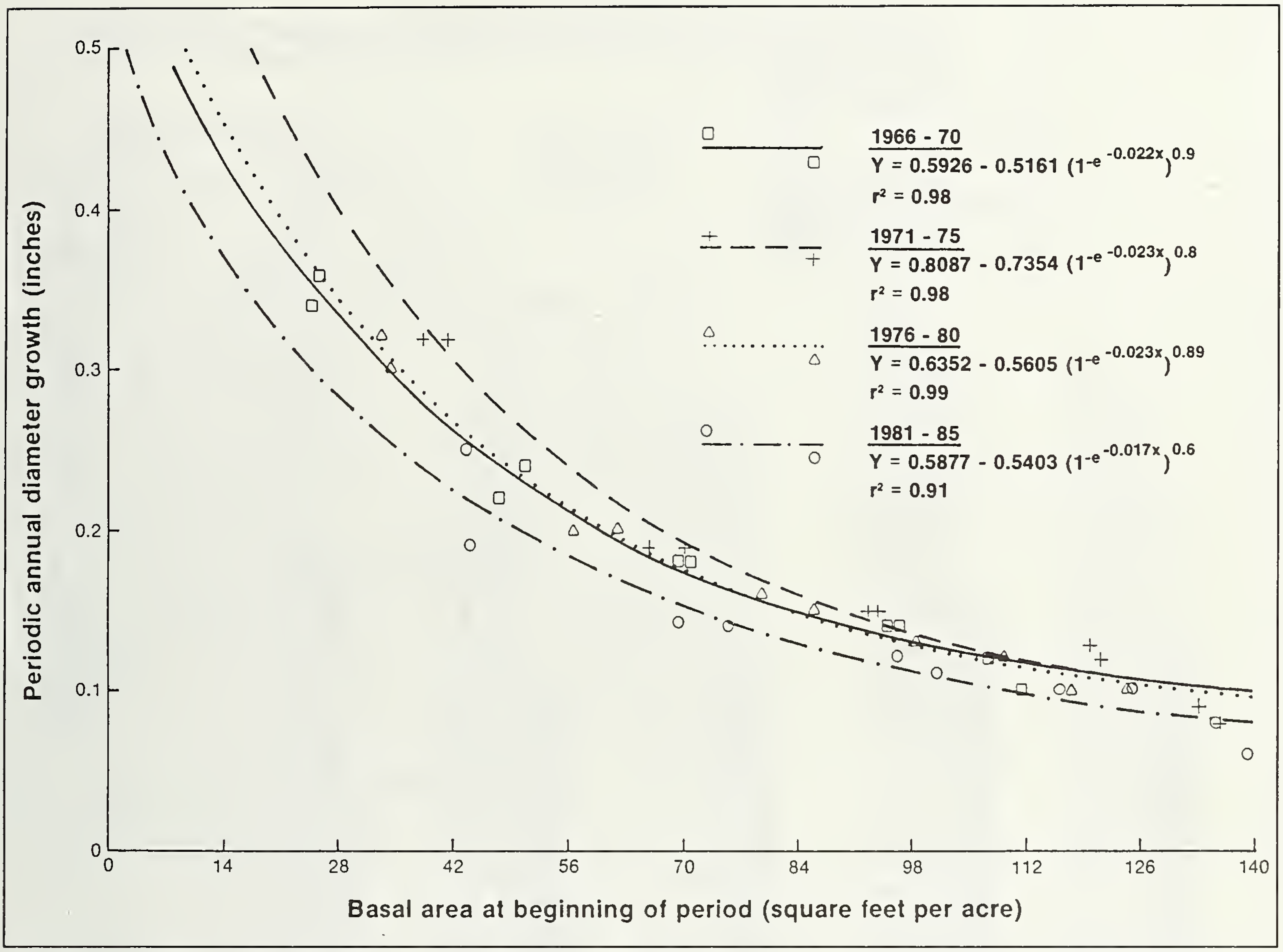

Figure 3—Periodic annual diameter growth by density level (basal area) and growth period.

Height Growth

Average annual height growth ranged from a low of 0.5-foot at the second-lowest density (fourth period) to a high of 1.6 feet at the lowest density (third period) (fig. 4). Height growth was relatively uniform among density levels, but a significant difference ($P<0.05$) in growth among levels occurred because of the slightly increased growth at the lowest level. Differences in height growth between periods also were significant ($P<0.05$); this was entirely the result of a pronounced decrease in growth during the fourth period. A severe ice storm in January 1984 did considerable damage to terminals so that average height growth was only about one-half that of the previous three periods. Height growth of larch and lodgepole pine was about the same during all periods.

Table 3—Increase in quadratic mean diameter of a western larch stand from 1966 to 1986 as a result of growth and 3 thinnings, by growth period and density level (bole area)

Bole-area level	Increase in quadratic mean diameter	Increase attributed to— Thinning	Growth	Growth
Thousand square feet per acre	*Inches*			*Percent*
	1966-70 (AGE 33-38)			
5	3.9	2.1	1.8	46
10	3.0	1.9	1.1	37
15	2.7	1.8	.9	33
20	2.0	1.3	.7	35
25	1.7	1.1	.6	35
	1971-75 (AGE 38-43)			
5	2.3	.7	1.6	70
10	1.6	.6	1.0	63
15	1.2	.5	.7	58
20	1.2	.6	.6	50
25	1.1	.7	.4	36
	1976-80 (AGE 43-48)			
5	1.5	0	1.5	100
10	1.1	0	1.1	100
15	.8	0	.8	100
20	.7	0	.7	100
25	.5	0	.5	100
	1981-85 (AGE 48-53)			
5	2.1	.9	1.2	57
10	1.0	.3	.7	70
15	1.0	.4	.6	60
20	1.1	.6	.5	46
25	.8	.3	.5	63
	1966-86 (AGE 33-53)			
5	9.8	3.7	6.1	62
10	6.7	2.8	3.9	58
15	5.7	2.7	3.0	53
20	5.0	2.5	2.5	50
25	4.1	2.1	2.0	49

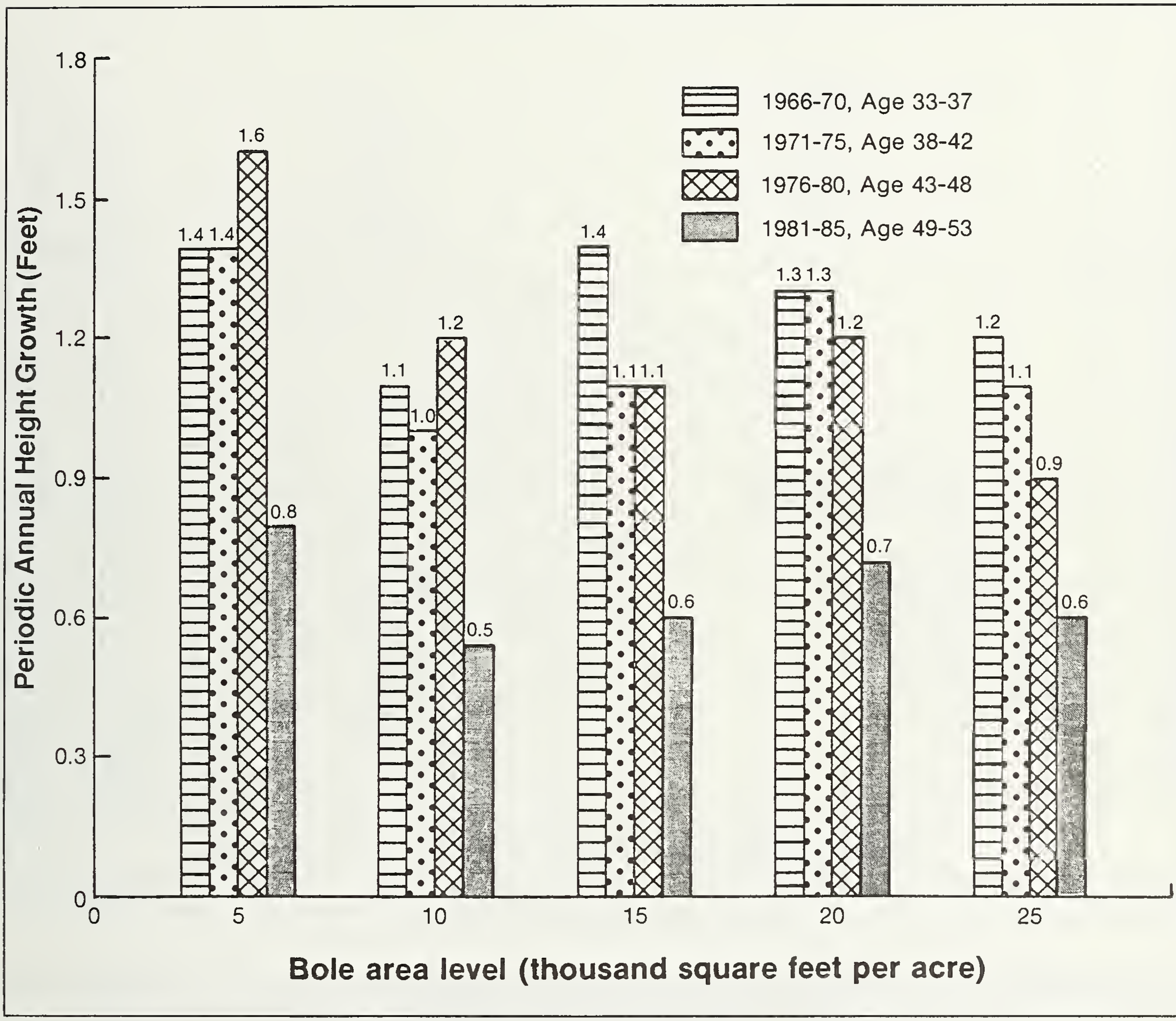

Figure 4—Periodic annual height growth by density level (bole area) and growth period.

Mortality

Mortality was light during the first 15 years of this study. Only 12 of 1,567 study trees died during the first period, 7 during the second period, and 3 during the third period; however, 58 trees died during the last 5 years of the study because the ice storm in 1984 broke tree boles below the live crown. All mortality occurred in the two highest density levels, except for 5 trees that died in a middle-density plot. Of the 1,567 trees present at the beginning of the study, 5 percent (80 trees) died during the 20 years of the study; 3.7 percent of this mortality was the result of the one ice storm in 1984. During the third period (1976-80), a light-to-moderate infestation of the larch casebearer (*Coleophora laricella* (Hübner)) occurred on all plots.

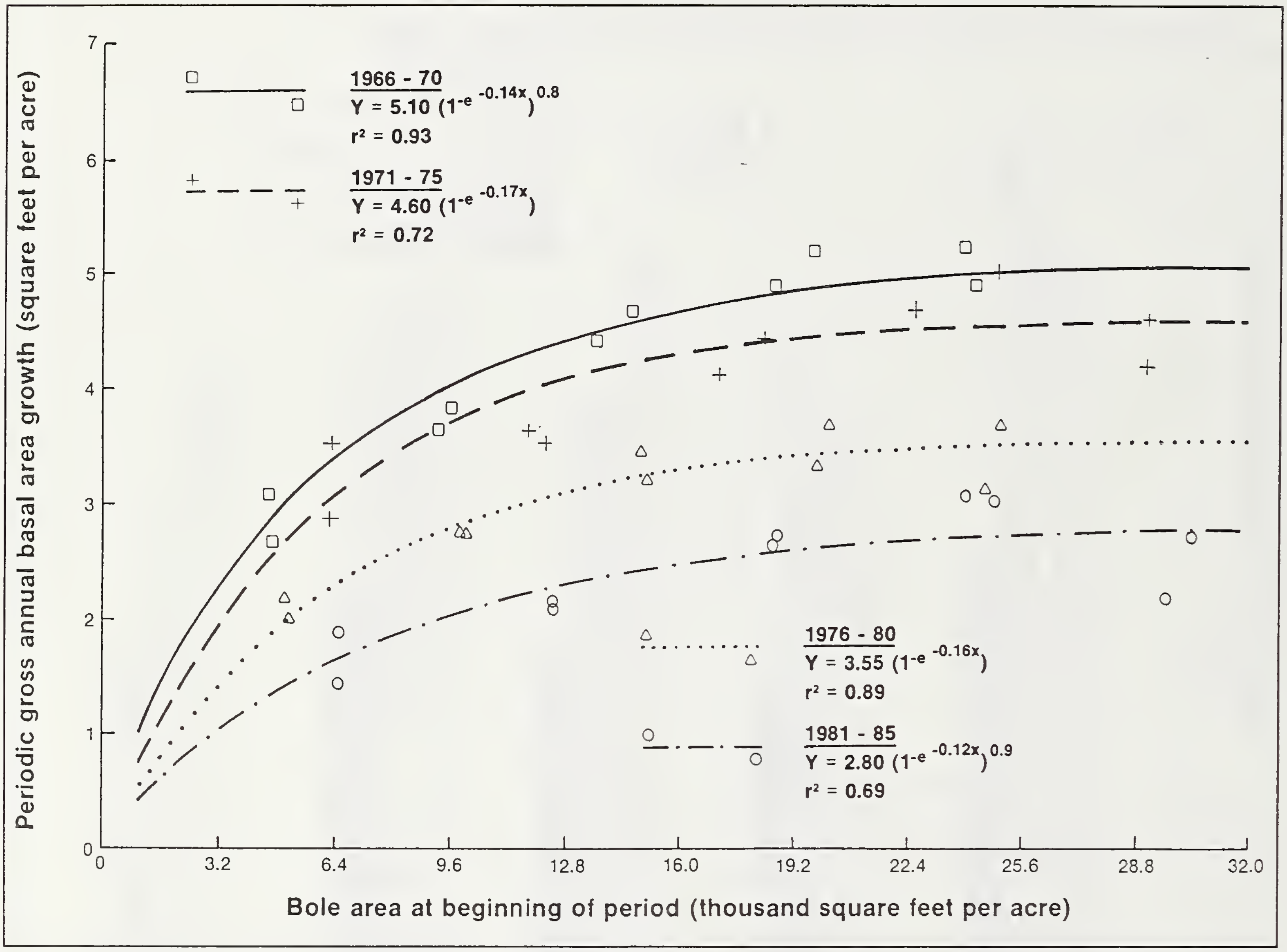

Figure 5—Periodic gross annual basal area growth by density level (bole area) and growth period.

Basal-Area Growth

Basal-area increment increased during all periods with increasing stand density, except for a slight decline at the highest density level during the last three periods (table 2). Differences in basal-area growth among density levels were significant ($P<0.01$). As expected, growth slowed significantly ($P<0.01$) from period to period as the stand became older (figs. 5 and 6). Averaged over all density levels, gross basal-area growth decreased from the first to the fourth period from 4.2 to 2.4 square feet per acre per year. During the fourth period, net basal-area growth at the highest density was almost zero because of the considerable mortality in these plots from the 1984 ice storm (table 2). Bole area and basal area were about equal as predictors of basal-area increment; each accounted for about 65 to 93 percent of the variation in growth. The interaction between stand density and growth period was also significant ($P<0.01$), primarily because of the increase in growth at the lowest density from the first to the second period in contrast to a decrease at the other four densities.

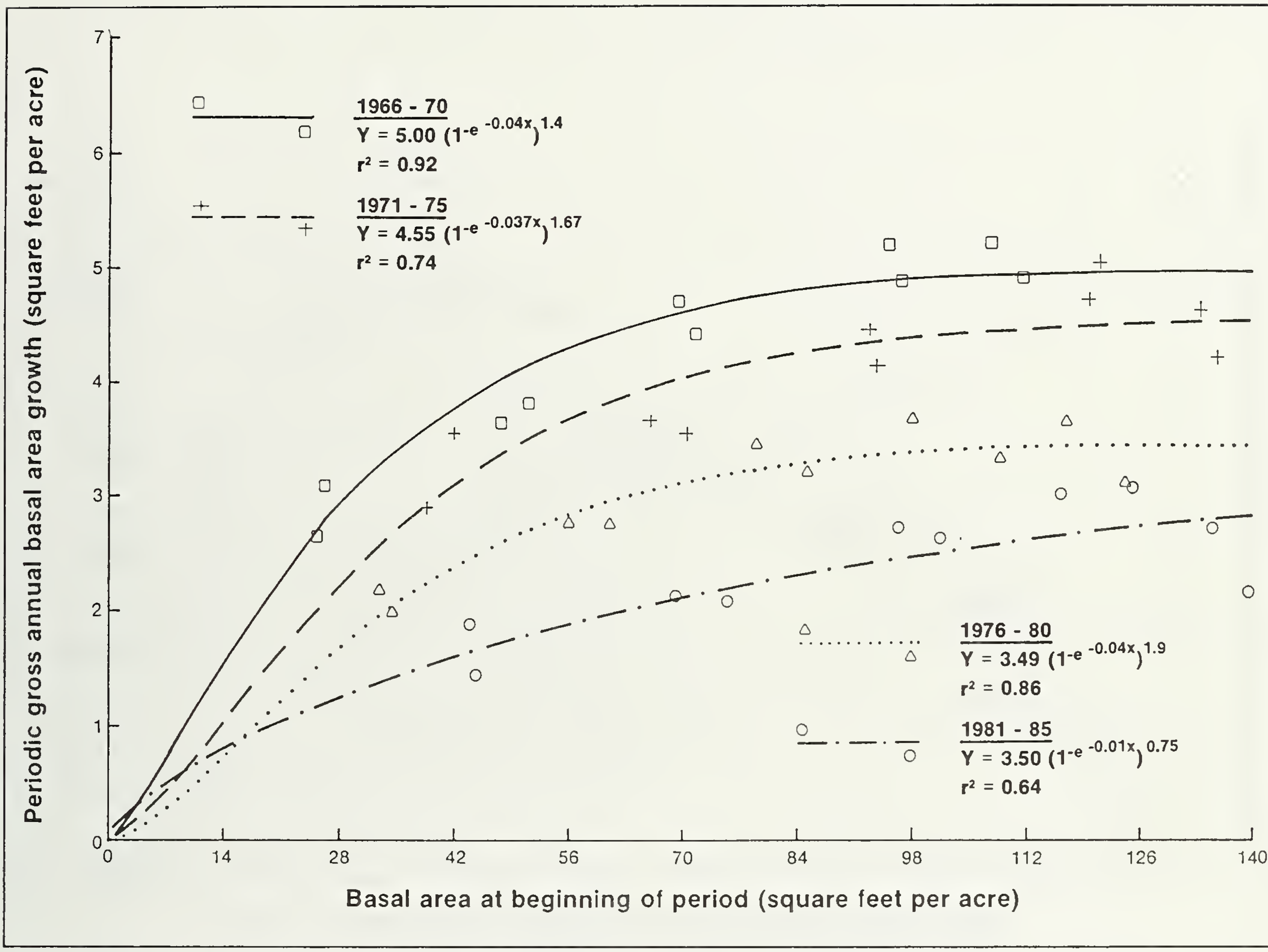

Figure 6—Periodic gross annual basal area growth by density level (basal area) and growth period.

Volume Growth

Total gross cubic-volume increment was excellent during the 20-year study, ranging from a low of 64 cubic feet per acre per year during the first period (level 1) to a high of 173 cubic feet per acre per year during the second period (level 4)(table 2). Gross and net volume growth were essentially the same except at levels 4 and 5 during the fourth period when net growth was reduced from 11 to 38 percent because of mortality from the ice storm. Averaged over all density levels, gross cubic increment increased significantly ($P<0.01$) from 104 cubic feet per acre per year during the first period to 134 cubic feet in the second period, declined slightly to 123 cubic feet during the third period, and to 114 cubic feet in the fourth period.

Gross volume growth increased in response to rising growing-stock levels during all periods (figs. 7 and 8). Although these curves show increasing growth over the range of stand densities tested, only a small increase in growth occurred from the fourth to the fifth density level compared to the more heavily thinned plots (table 2). This small increase suggests that full site use occurs as stand density approaches 30,000 square

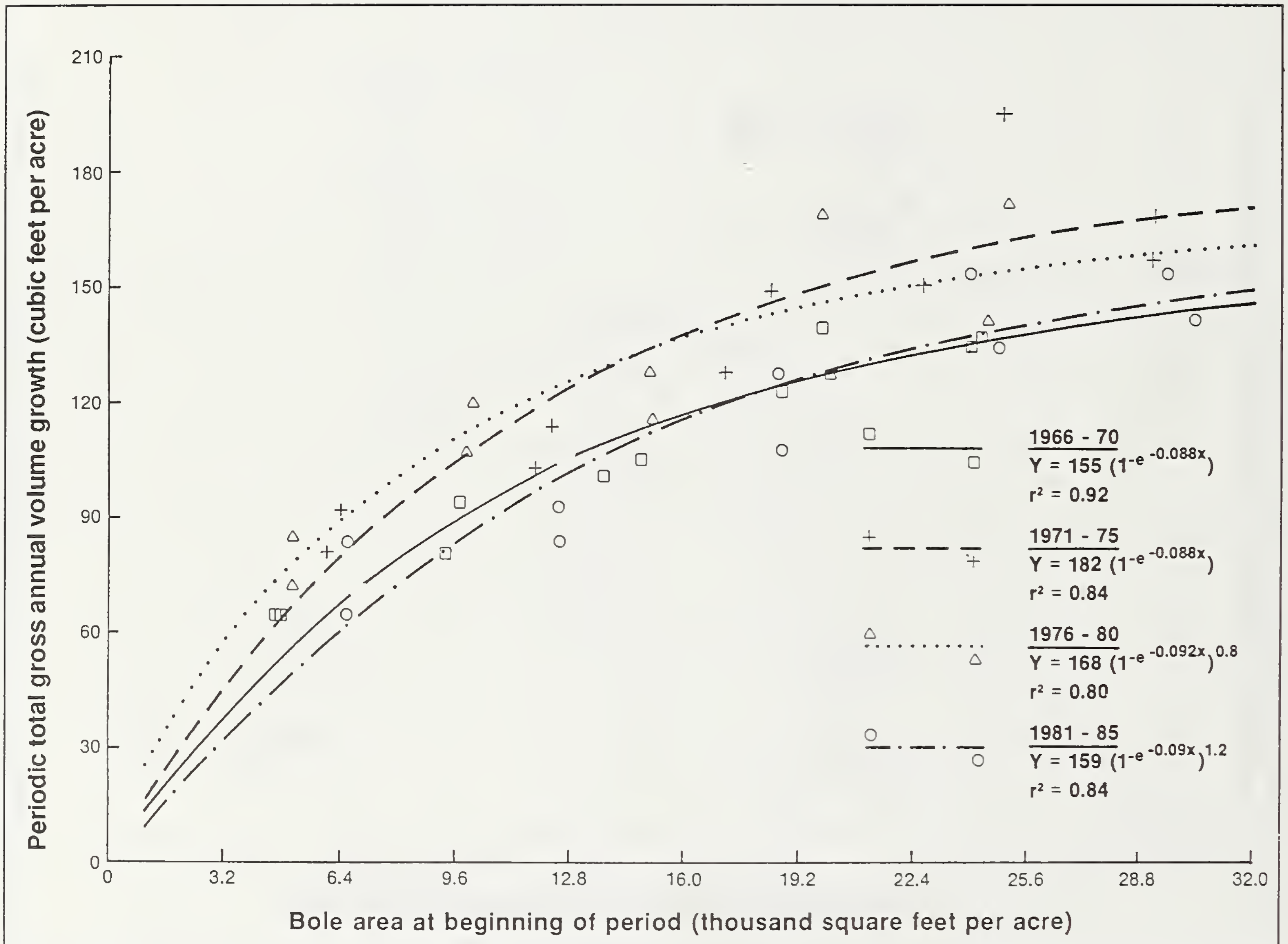

Figure 7—Periodic total gross annual cubic volume growth by density level (bole area) and growth period.

feet of bole area per acre and that increasing stocking beyond this level may not result in an increase in total volume increment. All growth differences among density levels were significant ($P<0.01$) except level 4 vs. level 5. Volume increment was about twice as great on the highest density plots as on the lowest during all periods; but much of the growth at high densities was distributed on more small, slow-growing trees.

Gross cubic-volume growth of the 75 largest trees per acre responded to stand density in the same manner as diameter growth did during all four periods—they grew faster at the lowest density level (table 2). Growth of these large trees was about twice as great at the lowest density than at the highest, which shows how growth is concentrated on the large trees in the low-density plots because of few competing trees.

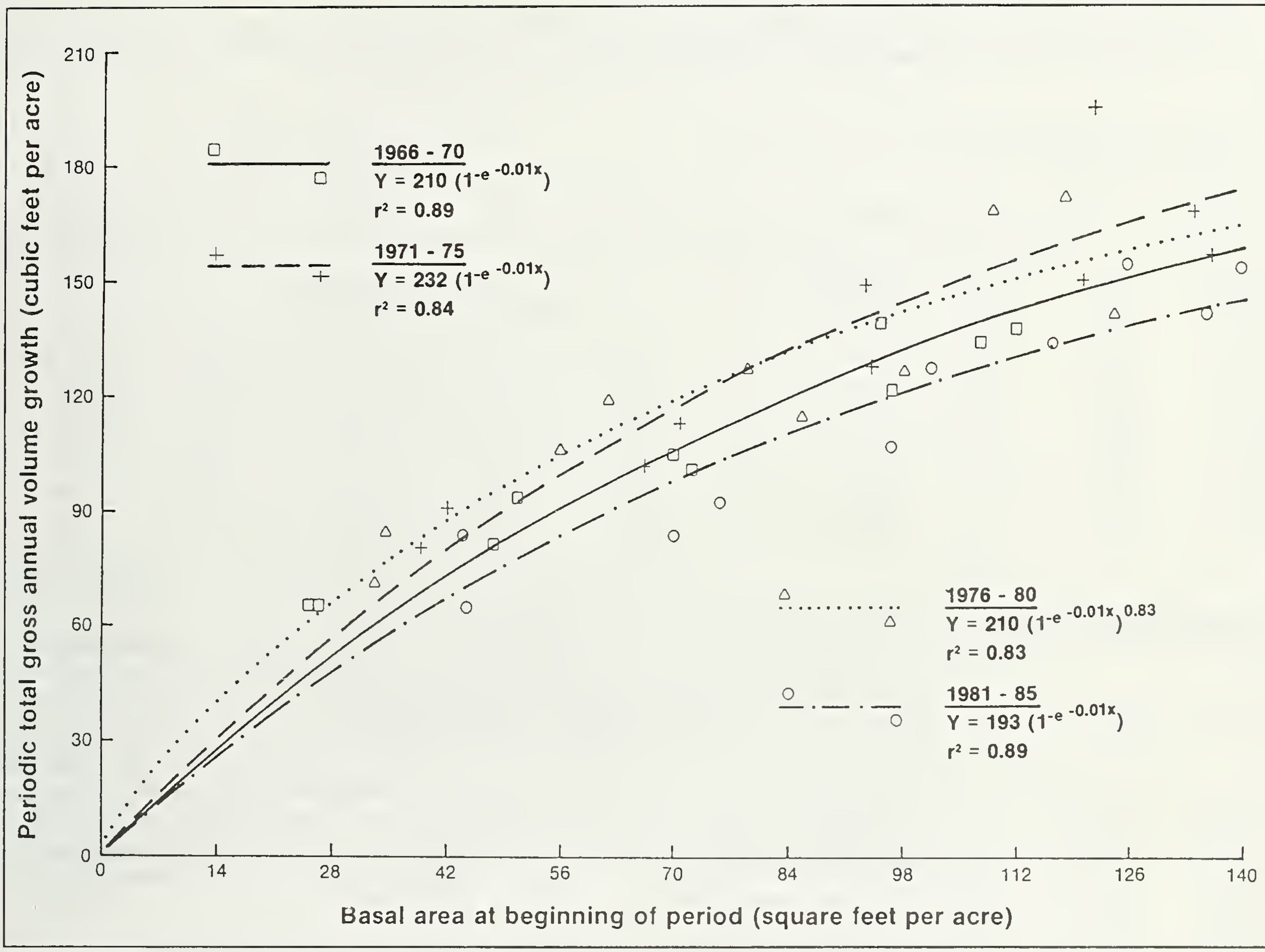

Figure 8—Periodic total gross annual cubic volume growth by density level (basal area) and growth period.

Board-foot volume increment increased from an average of 80 board feet per acre per year during the first period to 585 board feet per acre during the fourth period. All increases from period to period were significant ($P<0.01$). The more rapid diameter growth in low-density plots resulted in greater board-foot volume growth because more trees moved into merchantable size classes (ingrowth) and because of faster growth on trees already of saw-log size (10 inches d.b.h. or larger). Ingrowth accounted for about 90 percent of the board-foot volume growth during the first period and dropped to about 50 percent during the fourth period. Board-foot volume growth in the high-density plots is expected to increase rapidly in the future as many more trees reach saw-log size.

Mean annual cubic-foot increment is apparently nearing culmination (table 4), which agrees with data from yield tables for larch in Montana (Schmidt and others 1976) that show a 60- to 70-year culmination age.

Table 4—Net mean annual increment per acre of western larch by density level (bole area)

Bole-area level	Net mean annual increment by total age (years)				
	33	38	43	48	53
Thousand square feet per acre	*Cubic feet*				
5	60	61	64	65	66
10	69	72	76	80	80
15	72	76	83	87	89
20	70	78	89	95	98
25	67	75	85	93	93

Total Yield and Tree Size

Total net yield in cubic feet generally increased as stand density increased, although yield differences among the four highest levels were not large. In 1986, net yield ranged from 3,500 cubic feet per acre at the lowest density to 5,187 cubic feet at the second-highest and decreased slightly to 4,907 cubic feet at the highest (table 5). On the other hand, the greatest board-foot yield was at low stand densities and decreased considerably as stocking increased; the yields ranged from about 8,900 board feet per acre at the second-lowest density to about 3,000 board feet at the highest. Because essentially no board-foot volume was present on any of the plots at the beginning of the study, all the difference in yield can be attributed to the increased diameter growth at the low-density levels.

The quadratic mean diameter after thinning in 1986 ranged from 8.2 to 14.7 inches (tables 1 and 5). Because of differences in mean tree diameters, plots at the highest density contained more unmerchantable trees and, therefore, less merchantable volume from thinnings. For example, 41 trees per acre removed in the third thinning from the 10,000-square-foot density level yielded 1,719 board feet. In contrast, 95 trees per acre cut from the 25,000-square-foot level yielded only 129 board feet.

Table 5—Changes in number of trees, average diameter, cubic- and board-foot volumes (per acre), 1966 to 1986, resulting from 3 thinnings, by density level (bole area)

Item	Residual bole-area level (thousand square feet)				
	5	10	15	20	25
			Number of trees		
Total trees, 1966	924	1,161	1,406	1,377	1,459
Cut, 1966	828	946	1,051	831	714
Left, 1966	96	215	355	546	745
Cut, 1976	45	86	130	213	281
Left, 1976	51	129	225	333	464
Cut, 1986	19	41	73	100	95
Left, 1986	32	87	148	218	313
20-year mortality	0	1	4	15	56
			Inches		
Quadratic mean diameter after thinning in 1986	14.7	11.3	10.0	9.4	8.2
			Percent		
Trees 10 inches d.b.h. and larger after thinning in 1986	100	89.2	45.9	30.3	11.0
			Cubic feet		
Total volume:					
Total stand, 1966	1,995	2,287	2,367	2,322	2,200
Cut , 1966	1,521	1,385	1,095	706	353
Left, 1966	474	902	1,272	1,616	1,847
Cut, 1976	462	569	663	855	696
Left, 1976	760	1,301	1,808	2,248	2,621
Cut, 1986	449	623	756	848	617
Left, 1986	1,065	1,671	2,206	2,776	3,241
Net 20-year growth	1,505	1,959	2,353	2,865	2,707
Total net yield, 1986	3,500	4,246	4,720	5,187	4,907
			Board feet		
Merchantable volume:					
Total stand, 1966	48	0	193	0	0
Cut, 1966	0	0	0	0	0
Left, 1966	48	0	193	0	0
Cut, 1976	778	0	0	0	0
Left, 1976	2,876	2,366	1,464	1,168	706
Cut, 1986	2,120	1,719	1,053	359	129
Left, 1986	5,463	7,197	6,200	5,269	2,899
Net 20-year growth	8,315	8,914	7,060	5,627	3,040
Total net yield, 1986	8,363	8,914	7,253	5,627	3,040

Management Implications

After 20 years, this study clearly demonstrates the benefits of thinning from below so that growth is concentrated on a few, fast-growing trees. The diameter growth increased as stand density decreased, and the larger, more vigorous trees in these plots were better able to survive wind, snow, and ice storms than were the small trees.

Because the greatest diameter growth occurred at low stand densities and the greatest cubic volume growth at high densities, it is not possible to maximize both at the same time. The primary timber-management objective of precommercial thinning should be to stimulate diameter growth of residual trees so that merchantable products may be harvested sooner. Therefore, the stocking level left after precommercial thinning should depend on the manager's estimate of the minimum size tree (d.b.h.) that will be merchantable in the future. If markets for small trees exist and frequent commercial thinnings are possible to salvage dead trees, a high stand density is indicated to take advantage of the productive capacity of the site. If, on the other hand, no pulpwood market exists and the management objectives are to shorten the rotation and increase water and forage yields, a heavier precommercial thinning is necessary—with a sacrifice of some volume growth.

Because of the shade-intolerant nature of western larch, early thinning results in the greatest gains. Competition in young, overstocked larch stands results in reduction of the live crown followed by a decrease in diameter and height growth. Small, low-vigor trees also are less resistant to damage from wind, snow, insects, and diseases than are trees having adequate growing space. The ideal time for precommercial thinning of larch is when the trees are 10 to 15 years old and 10 to 15 feet tall. Care should be taken when thinning to cut trees below the lowest live branch to avoid having branches turn up.

After a stand has reached merchantable size, management goals should be to optimize volume and diameter growth and to salvage dead trees. Regulation of density in merchantable stands can be accomplished by applying the stocking-level curves for larch (Cochran 1985). These curves show that acceptable stocking levels include a wide range of stand densities; the choice depends on management objectives. It is therefore not critical to maintain an exact density at any time in the rotation, but rather to thin young stands to prevent excessive competition, which results in small crowns, loss of vigor, reduced growth, and increased mortality.

Conclusions

Early precommercial thinnings, when trees are 10 to 15 years old and 10 to 15 feet tall, are recommended for overstocked stands of larch. The selected spacing should result in a diameter growth rate that will allow merchantable trees to be cut in the next (commercial) thinning. By selecting a narrow spacing, the silviculturist is assuming that small trees will be salable at the time of the commercial thinning; conversely, by selecting a wide spacing one assumes that large trees are needed for the commercial thinning. After the stand reaches merchantable size, thinning from below to reduce basal area to the minimum stocking-level curve is recommended (Cochran 1985).

Metric Conversions

1 mile = 1.61 kilometers

1 foot = 0.3048 meter

1 inch = 2.54 centimeters

1 acre = 0.4047 hectare

1 square foot/acre = 0.2296 square meter/hectare

1 cubic foot/acre = 0.0700 cubic meter/hectare

1 tree/acre = 2.47 trees/hectare

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The 20-year growth response from a levels-of-growing-stock study in an even-aged western larch stand in eastern Oregon, first thinned at age 33, showed that trees growing at low stand densities grew more rapidly in diameter than trees in high-density plots. Height growth was relatively uniform among density levels. Both basal-area and total cubic-volume increment increased as stand density increased. Despite the large reduction in volume increment at the low densities, most of the wood is concentrated on a few, fast-growing trees that can reach usable size sooner than slow-growing trees in high-density plots.

Keywords: Increment (stand volume), even-aged stands, stand density, thinning effects, growing stock (-increment/yield, western larch, *Larix occidentalis*.

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November 1987

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